Lepton-Flavor Violating Processes $l_i \to l_j\gamma$ in Topcolor Assisted Technicolor Models

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Abstract

We consider the lepton-flavor violating(LFV) processes $l_i \to l_j\gamma$ in the framework of topcolor assisted technicolor(TC2) models. We find that the new gauge boson Z' predicted by TC2 models can give significantly contributions to these processes via the flavor changing couplings. The present experimental bound on the LFV process $\mu \to e\gamma$ gives severe constraints on the TC2 models. In the case that the Z' mass M_Z is consistent with other experimental constraints, we obtain constraints on the lepton mixing factors $K_{\tau\mu}$ and $K_{\tau e}$. The future LFV experiments will be probe of the TC2 models.

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1 Introduction

It is well known that the baryon and lepton numbers are automatically conserved and the tree level flavor changing neutral currents(FCNC's) are absent in the standard model(SM). The production cross section of the FCNC process is very small at one-loop level due to the unitary of CKM matrix. Thus, the FCNC processes can provide an important test for any new physics beyond the SM. Any observation of the flavor changing couplings deviated from that in the SM would unambiguously signal the presence of new physics.

The observation of neutrino oscillations[1, 2] implies that the individual lepton numbers $L_{e,\mu,\tau}$ are violated, suggesting the appearance of the lepton-flavor violating(LFV) processes, such as $\tau \to \mu\gamma$, $\tau \to e\gamma$ and $\mu \to e\gamma$. However, the branching ratios of these processes are extremely small in the SM with right-handed neutrinos. The present experimental limits[3] are:

$$B_r(\tau \to \mu\gamma) < 1.1 \times 10^{-6}, \quad B_r(\tau \to e\gamma) < 2.7 \times 10^{-6}, \quad B_r(\mu \to e\gamma) < 1.2 \times 10^{-11}. \tag{1}$$

Thus, the observation of any rate for one of these processes would be a signal of new physics. On very general grounds, theories of electroweak symmetry breaking(EWSB) often predict LFV effects within reach of the upcoming experiments[4]. This fact has led a lot of theoretical activity involving LFV processes within some specific models beyond the SM. For example, studies of LFV processes in supersymmetric(SUSY) models with a gauge unification group and SUSY models with "see-saw" neutrinos[5], SUSY models with R-parity violation[6], in models with extra dimensions[7] and in the Zee model[8].

The top quark, with a mass of the order of the weak scale, is singled out to play a key role in the dynamics of EWSB and flavor symmetry breaking. There may be a common origin for EWSB and top quark mass generation. Much theoretical work has been carried out in connection to the top quark and EWSB. The topcolor assisted technicolor(TC2) models[9], the top see-saw models[10] and the flavor universal coloron models[11] are three of such examples. These kinds of models generally predict the existence of colored gauge bosons (top-gluons, colorons), color-singlet gauge bosons (Z') and Pseudo Gold-

stone bosons. These new particles are most directly related to EWSB. Thus, studying the effects of these new particles in various processes would provide crucial information for EWSB and fermion flavor physics as well.

For TC2 models, the underlying interactions, topcolor interactions, are non-universal and therefore do not possess a GIM mechanism. When the non-universal interactions are written in the mass eigen-basis, it may lead to the flavor changing vertices of the new gauge bosons, such as $Z'\tau e$, $Z'\mu e$ and $Z'\mu\tau$. Thus the new gauge boson Z' might have significant contributions to some LFV processes[12, 13]. In this paper, we reexamine the contributions of the new gauge boson Z' to the LFV processes $l_i \to l_j\gamma(\tau \to \mu\gamma$, $\tau \to e\gamma$ and $\mu \to e\gamma)$ in the framework of TC2 models. We find that the present experimental bound on the LFV process $\mu \to e\gamma$ gives stringent constraints on the lepton mixing factors $K_{\tau\mu}$ and $K_{\tau e}$. For $M_Z = 3TeV$, $K_{\tau\mu} = 0.3$, there must be $K_{\tau e} < 0.07$ and for $M_Z = 3TeV$, $K_{\tau e} = 0.3$, there must be $K_{\tau\mu} < 0.07$.

The paper is organized as follows. In section 2 we give the widths and branching ratios of the LFV processes $l_i \to l_j\gamma$, which arise from the new gauge boson Z'. In section 3 we analyse the constraints on TC2 models from the current experimental bounds on the LFV processes $l_i \to l_j\gamma$ and compare them with that of the LFV process $\mu \to 3e$. Our conclusions are given in section 4.

2 The contributions of the new gauge boson Z' to the LFV processes $l_i \to l_j\gamma$

In TC2 models, the ETC interactions have contributions to all quark and lepton masses, while the mass of the top quark is mainly generated by the topcolor interactions, and EWSB is driven by technicolor or a Higgs sector. To maintain electroweak symmetry between top and bottom quarks and yet not generate $m_b \simeq m_t$, the topcolor gauge group is usually taken to be a strongly coupled $SU(3) \otimes U(1)$. The $U(1)$ provides the difference that causes only top quarks to condense. At the $\Lambda \sim 1TeV$, the dynamics of a general

TC2 model involves the following structure [9, 14]:

$$SU(3)_1 \otimes SU(3)_2 \otimes U(1)_{y_1} \otimes U(1)_{y_2} \otimes SU(2)_L \longrightarrow SU(3)_{QCD} \otimes U(1)_{EM}, \tag{2}$$

where $SU(3)_1 \otimes U(1)_{y_1}$ ($SU(3)_2 \otimes U(1)y_2$) generally couples preferentially to the third (first and second) generations. The $U(1)_{y_i}$ are just strongly rescaled versions of electroweak $U(1)_y$. This breaking scenario gives rise to the topcolor gauge bosons including the color-octet coloron B^A_μ and color-singlet extra $U(1)$ gauge boson Z'.

The flavor-diagonal couplings of the new gauge boson Z' to leptons, which are related to the LFV processes $l_i \rightarrow l_j \gamma$, can be written as:

$$\begin{aligned} \pounds^{FD}_{Z'} &= -\frac{1}{2} g_1 \cot\theta' Z'_\mu (\bar{\tau}_L \gamma^\mu \tau_L + 2\bar{\tau}_R \gamma^\mu \tau_R) \\ &+\frac{1}{2} g_1 \tan\theta' Z'_\mu (\bar{\mu}_L \gamma^\mu \mu_L + 2\bar{\mu}_R \gamma^\mu \mu_R + \bar{e}_L \gamma^\mu e_L + 2\bar{e}_R \gamma^\mu e_R), \end{aligned} \tag{3}$$

where g_1 is the $U(1)_y$ coupling constant at the scale Λ_{TC} and θ' is the mixing angle with $\tan\theta' = g_1/(2\sqrt{\pi K_1})$. For TC2 models, when the non-universal interactions, topcolor interactions, are written in the mass eigen-basis, it results in the flavor changing vertices of the gauge boson Z'. The flavor changing couplings of Z' to leptons can be written as:

$$\begin{aligned} \pounds^{FC}_{Z'} &= -\frac{1}{2} g_1 Z'_\mu [K_{\tau\mu} (\bar{\tau}_L \gamma^\mu \mu_L + 2\bar{\tau}_R \gamma^\mu \mu_R) \\ &+K_{\tau e} (\bar{\tau}_L \gamma^\mu e_L + 2\bar{\tau}_R \gamma^\mu e_R) + K_{\mu e} \tan^2\theta' (\bar{\mu}_L \gamma^\mu e_L + 2\bar{\mu}_R \gamma^\mu e_R)], \end{aligned} \tag{4}$$

where $K^{'s}_{ij}$ are the flavor mixing factors.

Using Eq.3 and Eq.4, we can calculate the contributions of the gauge boson Z' to the muon anomalous magnetic moment a_μ. The result has been given in Ref.[15], which is that, as long as the Z' mass $M_Z \geq 1TeV$, TC2 models could explain the observed BNL results of a_μ for $1.1TeV \leq M_{x_\mu} \leq 2.2TeV$. Now, we examine the LFV processes $l_i \rightarrow l_j \gamma (\tau \rightarrow \mu\gamma,\ \tau \rightarrow e\gamma,\ \mu \rightarrow e\gamma)$ which can be induced from the couplings $Z' l_i l_j$. A general form of the matrix element, which relates to the LFV processes $l_i \rightarrow l_j \gamma$, can be written as:

$$M = e\overline{u}(p_2) \sigma_{\mu\nu} q^\nu (A_L p_L + A_R p_R) u(p_1) \epsilon(q)^{*\mu}. \tag{5}$$

Using the formula given by Ref.[16] and Eq.3, Eq.4, the partial widths can be calculated:

$$\Gamma(\tau\to\mu\gamma)=\frac{\alpha^2 m_\tau^5}{1152\pi^2 M_Z^4 C_W^2}K_1 K_{\tau\mu}^2, \tag{6}$$

$$\Gamma(\tau\to e\gamma)=\frac{\alpha^2 m_\tau^5}{1152\pi^2 M_Z^4 C_W^2}K_1 K_{\tau e}^2, \tag{7}$$

$$\Gamma(\mu\to e\gamma)=\frac{\alpha^3 m_\mu^3 m_\tau^2}{512\pi^2 M_Z^4 C_W^4}K_{\tau\mu}^2 K_{\tau e}^2, \tag{8}$$

where α is the electromagnetic coupling constant, G_F is the Fermi constant and $S_W=\sin\theta_W$ which θ_W is the Weinberg angle. For TC2 models, to obtain the top quark direction for condensation, we must have $\cot\theta'\gg 1$. In above equations, we have ignored the high order terms which are proportional to $(\tan\theta')^2$ or $(\tan\theta')^4$ and approximately take $\theta'\approx\theta_W$.

The $e\bar{\nu}_e\nu_\mu$ is the dominant decay mode of the lepton μ. If we assume that the total decay width is dominated by the decay channel $\mu\to e\bar{\nu}_e\nu_\mu$, then we have:

$$B_r(\mu\to e\gamma)=\frac{\Gamma(\mu\to e\gamma)}{\Gamma(\mu\to e\bar{\nu}_e\nu_\mu)}=\frac{3\pi\alpha^3}{8G_F^2 C_W^4 M_Z^4}(\frac{m_\tau}{m_\mu})^2 K_{\tau\mu}^2 K_{\tau e}^2. \tag{9}$$

The $e\bar{\nu}_e\nu_\mu$ is one of the dominant decay modes of the lepton τ. The branching ratio $B_r(\tau\to e\bar{\nu}_e\nu_\tau)$ has been precisely measured, i.e. $B_r(\tau\to e\bar{\nu}_e\nu_\tau)=(17.83\pm 0.06)\%$ [3]. Thus, we can use the branching ratio $B_r(\tau\to e\bar{\nu}_e\nu_\tau)$ represent the branching ratios of the LFV processes $\tau\to\mu\gamma$ and $\tau\to e\gamma$.

$$B_r(\tau\to\mu\gamma)=\frac{\Gamma(\tau\to\mu\gamma)}{\Gamma(\tau\to e\bar{\nu}_e\nu_\tau)}\frac{\Gamma(\tau\to e\bar{\nu}_e\nu_\tau)}{\Gamma(\tau\to all)}=\frac{\pi\alpha^2 B_r(\tau\to e\bar{\nu}_e\nu_\tau)}{6G_F^2 C_W^2 M_Z^4}K_1 K_{\tau\mu}^2, \tag{10}$$

$$B_r(\tau\to e\gamma)=\frac{\pi\alpha^2 B_r(\tau\to e\bar{\nu}_e\nu_\tau)}{6G_F^2 C_W^2 M_Z^4}K_1 K_{\tau e}^2. \tag{11}$$

In the next section, we will use these formula given the constraints on the TC2 models from the current experimental bounds on the LFV processes $l_i\to l_j\gamma$.

3 Constraints on the TC2 models

The new strong interactions may exist at relatively low scales and may play an integral part in either EWSB or fermion mass generation. Thus, it is interesting to study current

experimental bounds on the mass of the corresponding gauge bosons. Ref.[17] gives the limits on the mass of the new gauge boson Z' via studying its corrections to the precisely measured electroweak quantities at LEP and its effects on bijet production and single top quark production at Tevatron. To see whether the precisely measured value of the branching ratio $B_r(\tau \rightarrow \mu\gamma)$ can give a bound on the Z' mass M_Z, we give the contour line of $B_r(\tau \rightarrow \mu\gamma) = 1.1 \times 10^{-6}$ in the (K_1, M_Z) plane for $0.2 \leq K_1 \leq 1$ and three values of $K_{\tau\mu}$ in Fig.1. From Fig.1 we can see that the bound on the Z' mass M_Z from the experimental value of $B_r(\tau \rightarrow \mu\gamma)$ is very weak. Even if we take the maximum values of the parameters, i.e. $(K_1)_{\max} = 1$[9] and $(K_{\tau\mu})_{\max} = \frac{1}{\sqrt{2}}$[5], we only have $M_Z > 397GeV$. From Eq.11, we can see that this conclusion is also applied to the LFV process $\tau \rightarrow e\gamma$. If we assume $K_{\tau e} \approx K_{\tau\mu} = \frac{1}{\sqrt{2}}$ and take $K_1 = 1$, $M_Z = 2TeV$, then we have $B_r(\tau \rightarrow \mu\gamma) = B_r(\tau \rightarrow e\gamma) \approx 1.7 \times 10^{-9}$, which are far below the present experimental upper bounds $(\sim 10^{-6})$[3]. Thus, the present experimental upper bounds on the LFV processes $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow e\gamma$ can not give significantly bounds on TC2 models.

From Eq.9 we can see that the values of the branching ratio $B_r(\mu \rightarrow e\gamma)$ given by the new gauge boson Z' depend on the Z' mass M_Z and the mixing factors $K_{\tau\mu}$ and $K_{\tau e}$. With reasonable values of M_Z (M_Z is consistent with other experimental constraints, such as LEP and Tevatron experiments[17]), the current experimental upper bound on the branching ratio $B_r(\mu \rightarrow e\gamma)$ can give constraints on the lepton mixing factors $K_{\tau\mu}$ and $K_{\tau e}$, which are symmetric on both factors. In Fig.2, we present our numerical results, which shows upper bounds on $K_{\tau\mu}$ and $K_{\tau e}$ from $B_r^{exp} < 1.2 \times 10^{-11}$, for $M_Z = 2TeV$, $3TeV$ and $5TeV$. From Fig.2 we can see that the present experimental upper limit on the $B_r(\mu \rightarrow e\gamma)$ can put severe constraints on $K_{\tau\mu}$ and $K_{\tau e}$. If we take $K_{\tau\mu} = 0.3$, $M_Z = 3TeV$, there must be $K_{\tau e} < 0.07$, and for $K_{\tau e} = 0.3$, $M_Z = 3TeV$, there must be $K_{\tau\mu} < 0.07$.

Comparing the contribution of Z' to the LFV process $\mu \rightarrow 3e$ to that of muon decay process $\mu \rightarrow e\bar{\nu}_e\nu_\tau$, which proceeds via the electroweak gauge boson W exchange, we give the branching ratio $B_r(\mu \rightarrow 3e)$ arising from the Z' exchange[13]. Using $K_1 \approx \frac{g_1^2 \tan^2\theta'}{4\pi}$

and $M_W^2 = \frac{\sqrt{2}g_2^2}{8G_F}$, Eq.10 of Ref.[13] can be rewritten as:

$$B_r(\mu \rightarrow 3e) = \frac{\Gamma(\mu \rightarrow 3e)}{\Gamma(\mu \rightarrow e\bar{\nu}_e\nu_\tau)} = \frac{25\pi^2\alpha^2 \tan^4\theta_W}{128G_F^2C_W^4M_Z^4}K_{\mu e}^2. \tag{12}$$

In Fig.3 we give the contour lines of $B_r(\mu \rightarrow e\gamma) = 1.2 \times 10^{-11}$ and $B_r(\mu \rightarrow 3e) = 1.2 \times 10^{-12}$ in the (K, M_Z) plane for $K_{\tau\mu} \approx K_{\tau e} = K$, which is in the range of $0.02 \leq K \leq 0.4$. From Fig.3, we can see that the upper experimental limits of $B_r(\mu \rightarrow e\gamma)$ and $B_r(\mu \rightarrow 3e)$ demand that M_Z is larger than $0.41TeV$ for $K_{\tau\mu} \approx K_{\tau e} = K > 0.02$ and $1.42TeV$ for $K_{\mu e} > 0.02$, respectively. For $K_{\mu e} = \lambda = 0.22$, M_Z must be larger than $4.7TeV$, which is consistent with the conclusion of Ref.[18]. This conclusion is independent of the parameter K_1. For $K_{\tau\mu} = K_{\tau e} \leq 0.25$ and $K_{\mu e} \leq 0.25$, the constraints from the precision experimental value of $B_r(\mu \rightarrow 3e)$ on TC2 models are stronger than that of $B_r(\mu \rightarrow e\gamma)$.

Similarly, we can calculate the contributions of the new gauge boson Z' to the LFV processes $\tau \rightarrow l_il_jl_k(\tau \rightarrow 3e,\ \tau \rightarrow ee\mu,\ \tau \rightarrow e\mu\mu$ and $\tau \rightarrow 3\mu)$. Using the present experimental upper bounds on the branching ratios of these processes, we can obtain upper bounds on the mixing factor $K_{\tau e}$, $K_{\tau\mu}$ or $K_{\mu e}$. However, the present experimental upper bounds on the branching ratios $B_r(\tau \rightarrow l_il_jl_k)$ are of order 10^{-6}, which are weaker than those of the LFV processes $\mu \rightarrow 3e$ and $\mu \rightarrow e\gamma$. Thus, compared to the LFV processes $\mu \rightarrow 3e$ and $\mu \rightarrow e\gamma$, these processes can not give stringent bounds on TC2 models.

4 Conclusions

TC2 theory is an attractive scheme in which there is an explicit dynamical mechanism for breaking electroweak symmetry and generating the fermion masses including the heavy top quark mass. This kind of models predict the flavor changing coupling vertices of the new gauge bosons, such as $Z'\mu e$, $Z'\tau\mu$ and $Z'\tau e$. In this paper, we calculate the effects of these couplings on the LFV processes. We find that these virtual effects on the LFV processes $\tau \rightarrow e\gamma$, $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow l_il_jl_k$ are far below the present experimental upper limits on these processes. However, the present experimental upper bound on the

branching ratio $B_r(\mu \to e\gamma)$ gives severe constraints on TC2 models. In the case that the Z' mass M_Z is consistent with other experimental constraints, we obtain stringent constraints on the lepton mixing factors $K_{\tau\mu}$ and $K_{\tau e}$. However, if we assume $K_{\tau\mu} = K_{\tau e} \leq 0.25$ and $K_{\mu e} \leq 0.25$, we find that the LFV process $\mu \to 3e$ can give more severe bound on M_Z than that of the LFV process $\mu \to e\gamma$. The constraints from $\mu \to 3e$ on TC2 models are stronger than that of $\mu \to e\gamma$. In the near future, the LFV experiments will increase the sensitivity to the LFV processes by four or more orders of magnitude. Thus, the future LFV experiments will be probes of TC2 models.

Figure captions

Fig.1: The contour line of $B_r(\tau \to \mu\gamma) = 1.1 \times 10^{-6}$ in the $(K_1,\, M_Z)$ plane for $K_{\tau\mu} = 0.707$(solid line), 0.25(dotted-dashed line) and 0.1(dashed line).

Fig.2: The contour line of $B_r(\mu \to e\gamma) = 1.2 \times 10^{-11}$ in the $(K_{\tau\mu},\, K_{\tau e})$ plane for $M_Z = 5TeV$ (solid line), $3TeV$(dotted line) and $2TeV$(dotted-dashed line).

Fig.3: The contour lines of $B_r(\mu \to e\gamma) = 1.2 \times 10^{-11}$ and $B_r(\mu \to 3e) = 1.2 \times 10^{-12}$ in the $(K,\, M_Z)$ plane for $K_{\tau\mu} \approx K_{\tau e} = K$.

References

[1] Y. Fukudo et al. (The Super-Kamiokande Collaboration), *Phys. Lett. B***436**, 33(1998), *Phys. Rev. Lett.* **81**, 1562(1998); *ibid* **85**, 3999(2000).

[2] P. Anselmann et al. [GALLEX Collaboration.], *Phys. Lett. B***342**, 440(1995); K. Lande et al., *Astrophys. J* **496**, 505(1998); Y. Fukudo et al. [Super-Kamiokande Collaboration], *Phys. Rev. Lett.***82**, 1810(1999).

[3] Particle Data Group, *Euro. Phys. J. C***15**, 1(2000).

[4] J. L. Feng, hep-ph/0101122.

[5] F. Borzumati and A. Masiero, *Phys. Rev. Lett.***57**, 961(1986); J. Hisano, T. Moroi, K. Tobe ana M. Yamaguchi, *Phys. Rev. D***53**, 2442(1996); S. F. King and M. Oliveira, *Phys. Rev. D***60**, 035003(1999); J. Hisano and D. Nomura, *Phys. Rev. D***59**, 116005(1999); hep-ph/0004061; J. Sato, K. Tobe, and T. Yanagida, *Phys. Lett. B***498**, 189(2001); D. F. Carvalho, M. E. Gomez, and S. Khalil, hep-ph/0101250; Zi-Zhong Xing, *Phys. Rev. D***64**, 017304(2001); J. A. Casas and A. Ibarra, hep-ph/0103065; D. F. Carvalho, J. Eillis, M. E. Gomez and S. Lola, hep-ph/0103256.

[6] M. Frank, *Phys. Rev. D***62**, 015006(2000); A. de Couvea, S. Lola and K. Tobe, *Phys. Rev. D***63**, 035004(2001).

[7] R. Kitano, *Phys. Lett. B***481**, 39(2000); F del Aguila and J. Santiago, *Phys. Lett. B***493**, 175(2000).

[8] S. T. Petcov, *Phys. Lett. B***115**, 401(1982); S. T. Petcov, *Rev. Mod. Phys.***59**, 671(1987); A. Yu Simirnov, M. Tanimoto, *Phys. Rev. D***55**, 1665(1997); G. C. Mclaughlin, J. N. Ng, *Phys. Lett. B***455**, 224(1999); E. Mituda and K. Saski, hep-ph/0103202.

[9] C. T. Hill, *Phys. Lett. B***345**, 483(1995); K. Lane and E. Eichten, *Phys. Lett. B***352**, 383(1995); K. Lane, *Phys. Lett. B***433**, 96(1998) G. Cvetic, *Rev. Mod. Phys.* **71**, 513(1999).

[10] B. Dobrescu, C. T. Hill, *Phys. Rev. Lett.***81**, 2634(1998); R. S. Chivukula, B. Dobrescu, H. Georgi, C. T. Hill, *Phys. Rev. D***59**, 075003(1999).

[11] M. B. Popovic, E. H. Simmons, *Phys. Rev. D***58**, 095007(1998); K. Lane, *Phys. Lett. B***433**, 96(1998); G. Burdman, N. Evans, *Phys. Rev. D***59**, 115005(1999).

[12] T. Rador, *Phys. Rev. D***60**,095012(1999).

[13] Chongxing Yue, Guoli Liu and Jiantao Li, *Phys. Lett. B***496**, 89(2000).

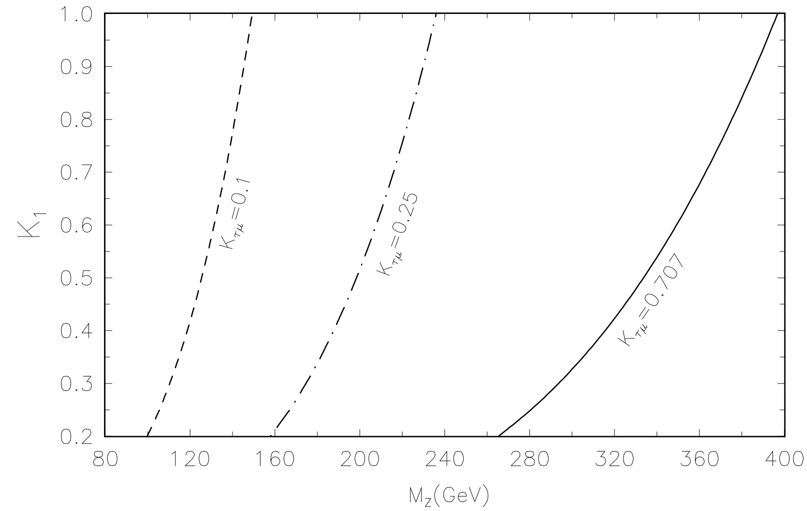
[14] G. Buchalla, G. Burdman, C. T. Hill, D. Kominis, *Phys. Rev. D***53**, 5185(1996).

[15] Chongxing Yue, Qingjun Xu, Guoli Liu, *J. Phys. G***27**, 1807(2001).

[16] M. Sher and Y. Yuan, *Phys. Rev. D***44**, 1461(1991).

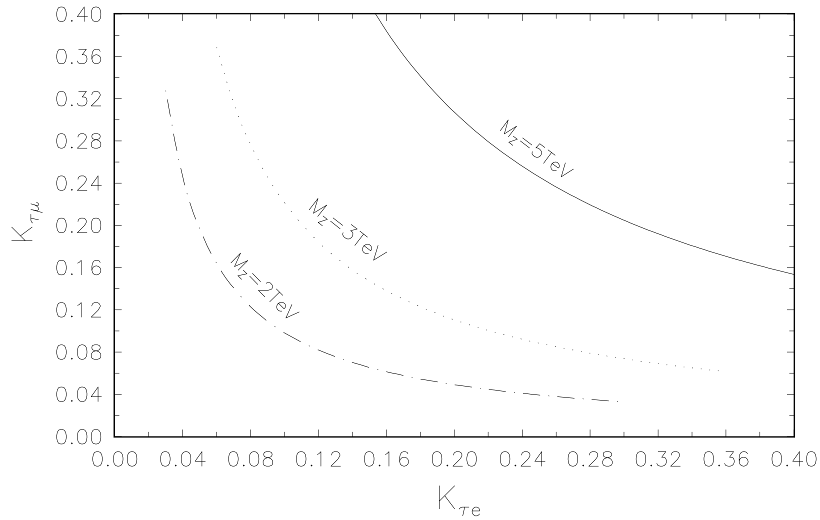
[17] G. Burdman, R. S. Chivukula, N. Evans, *Phys. Rev. D***61**, 035009(2000); G. Burdman, R. S. Chivukula, N. Evans, *Phys. Rev. D***62**, 075007(2000).

[18] G. Burdman, K. Lane, T. Rador, *Phys. lett. B* **514**, 41(2001).



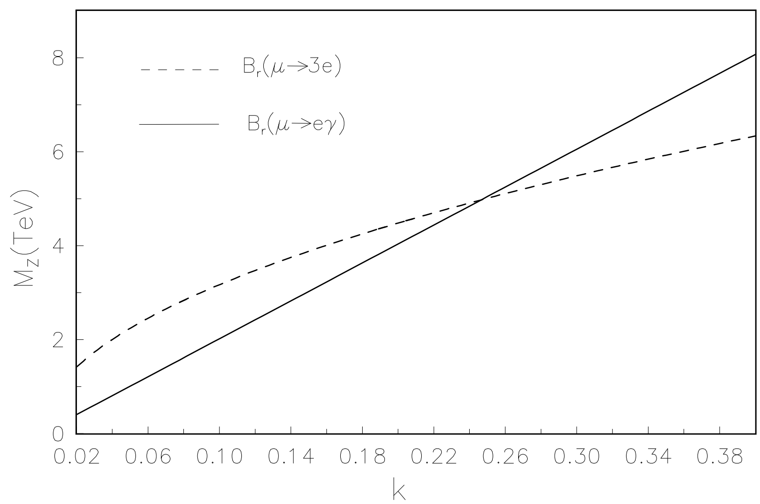
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
K1
80
120
160
200
240
280
320
360
400
Mz(GeV)
Kτμ=0.1
Kτμ=0.25
Kτμ=0.707

Fig.1



0.40
0.36
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
Kτμ
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.32
0.36
0.40
Kτe
Mz=5TeV
Mz=3TeV
Mz=2TeV

Fig.2



$B_r(\mu \to 3e)$
$B_r(\mu \to e\gamma)$
M_Z(TeV)
8
6
4
2
0
0.02
0.06
0.10
0.14
0.18
0.22
0.26
0.30
0.34
0.38
k

Fig.3